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Evaluation of the Two Phase Pressure Drop during the CO_2-N_2 Mixture Pipeline Transport

Meang-Ik Cho[a], Cheol Huh[a]*, Seong-Gil Kang[a], Jong-Hwa Baek[a],

[a]*Offshore CCS Research Unit, Korea Research Institute of Ships & Ocean Engineering(KRISO)*
32 1312beon-gil, Yuseong-daero, Yuseong-gu, Daejeon, 305-343, Republic of Korea

Abstract

Captured CO_2 mixture for sequestration purpose can contain impurities such as N_2, NOx, SOx, O_2, H_2O, H_2, H_2S, Ar. Such impurities affect the critical temperature and pressure, density, viscosity, saturation temperature-pressure line, etc. Among the impurities, N_2 can affect the CO_2 stream properties largely cause of the low boiling point and high specific volume, so a small ratio of N_2 inflow might change the flow pattern of CO_2 stream from single phase to two phase flow. To understand the flow behavior of two phase CO_2 stream with N_2 impurity, experimental investigations should be carried out and compared with existing correlation to figure out the accuracy of correlations. In this study we designed and installed an experimental facility to simulate the two phase flow behavior of CO2-N_2 mixture during the pipeline transportation. The test section is composed of a single 6 meter STS304 tube with inner diameter of 3.8608mm with inlet absolute pressure transmitter and inlet-outlet differential pressure transmitter. Test condition was 21 ℃ and 85 bar with varying N_2 impurity ratio. In this study the two-phase flow pressure drop data of CO_2-N_2 mixture flow are compared with correlations of Lockhart-Martinelli, Zhang et al, and Misima & Hibiki. Among three candidate correlations Mishima & Hibiki correlation showed the best accuracy. All of three correlations showed rather low accuracy, but it might be from the reason that the correlations were originally designed to estimate water-vapor two-phase flow pressure drop. The result also shows the need to investigate further visualization and flow pattern identification.

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Keywords: Carbon dioxide Capture and Storage(CCS); N_2 impurity; Steady flow; Two-phase flow; CO_2 transport; Pipeline Transport

* Corresponding author. Tel.: +82-42-866-3622; fax: +82-42-866-3631.
E-mail address: chuh@kriso.re.kr

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1. Introduction

CCS is assumed as one of key technologies to mitigate global warming and climate change. In 2050, it is estimated as CCS will reduce about 19% of greenhouse gas. So many countries are investing on CCS technology with vast budget. CCS is mainly composed of three processes which are capture process, transport process, and inject & storing process. In capture process, CO_2 is separated from exhaust gas from power plant or steel making company, then, the captured CO_2 stream is transported to storage site to be finally injected and stored in safe geological structure. By the way, in the CO_2 stream of CCS, the impurities included during power generation and capture process does coexist and stored in the storage sites. The impurities such as NOx, Sox, N_2, O_2, H_2, Ar, etc effect on the physical properties like density, viscosity, critical point, saturation pressure. The effects on the density would decrease storage efficiency of geological formation and also increase the capture and transport process cost both of CAPEX and OPEX. Although the effect of impurities as mentioned above is important, the accurate and quantitative analysis is not accumulated enough. Huh et eal.[1] and Cho et al.[2] conducted the steady state flow experiment, including two phase flow region, discussing water and N_2 impurity effect of thermodynamic property change and pressure drop change. This study is extended analysis of the previous researches especially on the two phase flow region[3].

2. Experimental Facility and Test Condition

The detailed description of experimental facility was introduced on the previous researches[2, 3], but for the purpose of increasing readability descriptions are introduced below again concisely. The facility is comprised of four main modules: a CO_2 compression module, N_2 Compression module, mixing module, and test section. The CO_2 compression module pressurizes gaseous CO_2 into high pressure. The pressurized CO_2 then be cooled and liquefied with high pressure heat exchanger and coolant before supplied into mixing module. N_2 also pressurized and supplied into mixing module. In mixing module both CO_2 and N_2 flow rates are measured with mass flow meter then mixed in mixing zone made of T shape union fitting. The CO_2-N_2 mixture then flow into preheater which control the fluid temperature as test condition. The test section is stainless steel seamless tube with inner diameter of 3.8608 mm, 6,000 mm length. The same inner diameter tube is installed just before test section to build the flow pattern as fully developed.

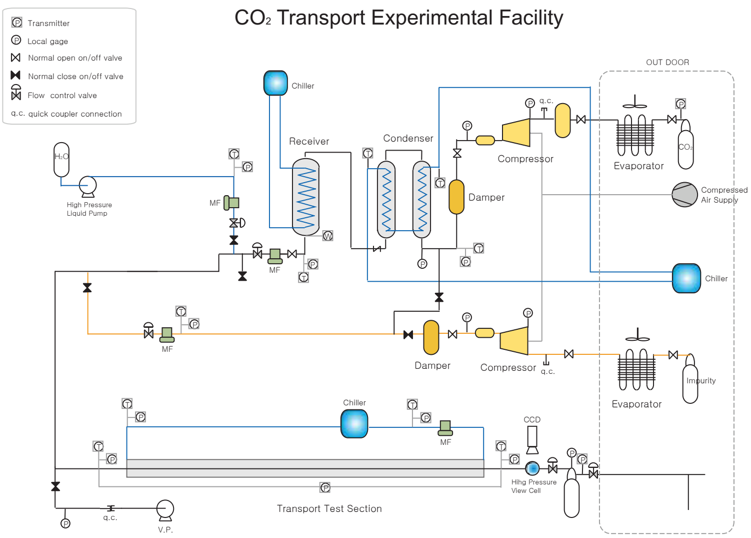

Fig 1. Schematic diagram of experimental facility[3]

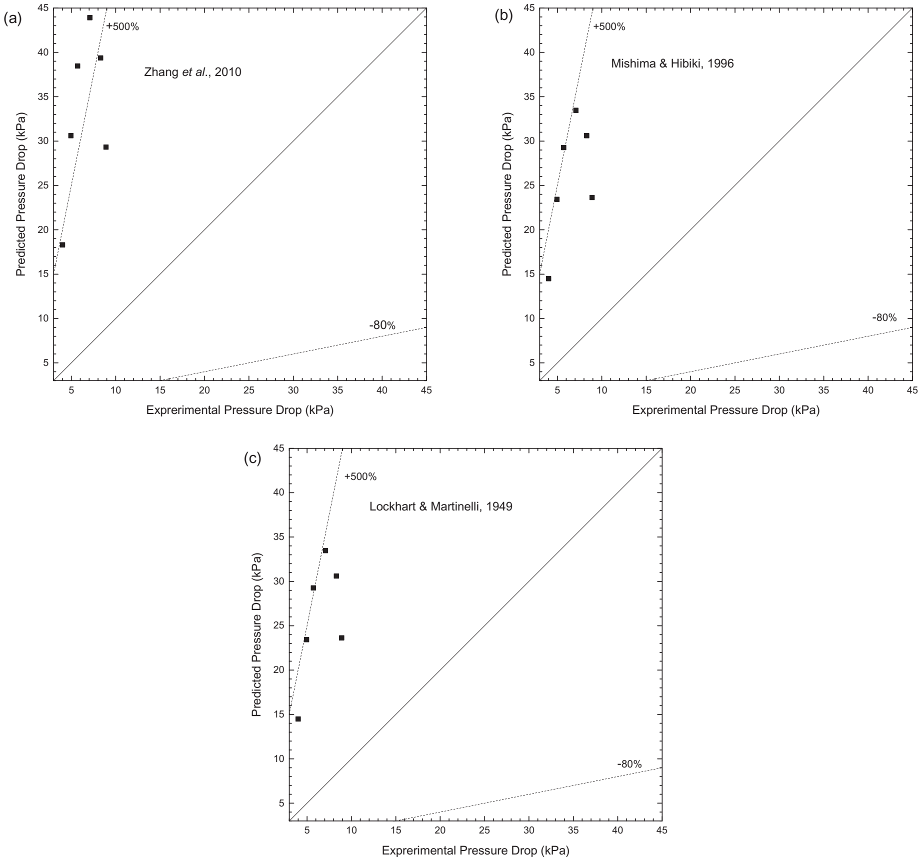

Fig 2. Comparison of experimental data with predictions of (a) Zhang et al correlation; (b) Mishima & Hibiki correlation; (c) Lockhart & Martinelli correlation

The steady state flow experiment of CO_2-N_2 mixture fluid was conducted with temperature of 21 ℃, and pressure of 70 bar condition. The manual metering valve was manipulated to set flow rate condition as 17.2kg/hr total inspite of variation of CO_2 and N_2 flow rate. The differential pressure and absolute inlet pressure data were logged by NI cDAQ and LabView program along with inlet and outlet temperature. The steady state was assumed as inlet pressure, differential pressure, flow rate of both CO_2 and N_2, and temperature were stable and fluctuated in less than 1% range over 7 minutes.

3. Result

In this study the two-phase flow pressure drop data of CO_2-N_2 mixture flow are compared with correlations of Lockhart-Martinelli[4], Zhang et al[5], and Misima & Hibiki[6]. The correlations mentioned above showed over prediction and the mean absolute percentage error (MAPE) values of each correlation are shown in table xx. The reason of rather large MAPE value might be originated from the fact that the correlations were developed to apply to water-vapor or air-water two-phase flow , therefore, three correlations didn't show good prediction capability for CO_2

or CO_2-N_2 mixture flow. Though the MAPE values are not small, the result of Mishima & Hibiki correlation among three correlations showed the best accuracy, and, Zhang et al correlation and Lockhart-Martinelli correlation showed similar accuracy following the Mishima & Hibiki correlation accuracy.

Table 1. Mean absolute percentage error of two-phase pressure drop correlations

Correlations	MAPE*
Zhang et al	428%
Mishima & Hibiki	308%
Lockhart & Martinelli	423%

$$MAPE = \frac{1}{n}\sum \frac{\left|A_{\exp} - A_{cal}\right|}{A_{\exp}} \times 100\%$$

The two-phase flow pattern was also recorded by CCD camera. As shown in Fig 3, the view cell geometry is not the same as that of test section, but the observed result shows that two-phase flow occurred in test section. The photographs shows that as vapor quality increases the observed liquid hold-up in view cell decreased. The result shows the need to build same geometry view cell as test section and mount high speed CCD to capture the high speed flow pattern. This will be done in future work.

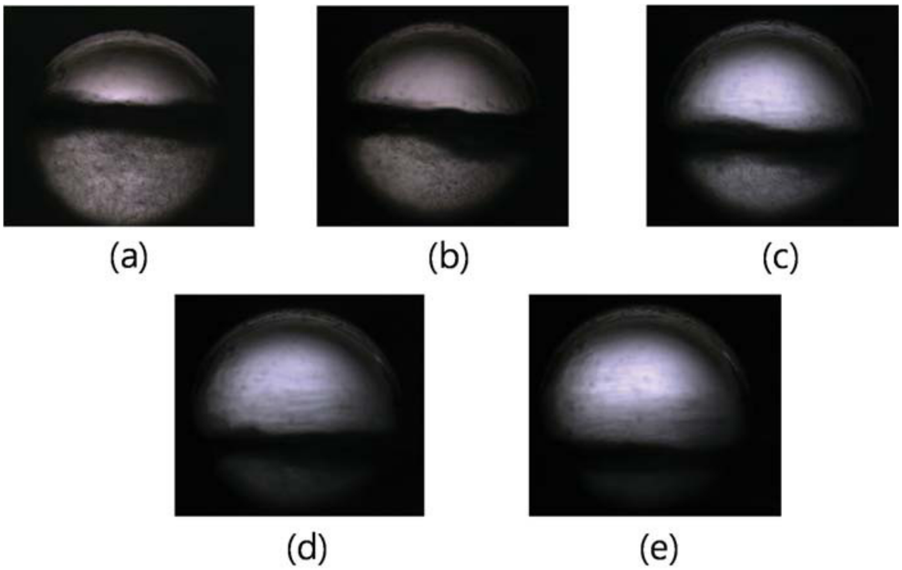

Fig 3. Two-phase flow obervation result with varying vapour quality(x) as (a) x = 0.20; (b) x = 0.31; (c) x = 0.53; (d) x = 0.72; (e) x = 0.85

4. Conclusion

The two-phase flow pressure drop data of CO_2-N_2 mixture flow were compared with predictions of correlations. Among three candidate correlations Mishima & Hibiki correlation showed the best accuracy. All of three correlations showed rather low accuracy, but it might be from the reason that the correlations were originally designed to estimate water-vapor two-phase flow pressure drop. The observed flow pattern resulted in the straight forward fact that as vapor quality increases the liquid holdup in view cell decreases. In the future work, more correlations designed for CO_2 or N_2 two-phase flow will be compared with experimental data, and updated view cell will be built up to observe in-situ flow pattern visualization which might realize applying phenomenological based correlation to estimate pressure drop and flow behavior.

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